

# Software Design, Modelling and Analysis in UML

## Lecture 03: Object Constraint Language

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### Content

- The Object Constraint Language (OCL)
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  - Running Example
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  - Context
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  - The Running Example Revisited
- "Not interesting?"

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### Overview

$expr ::=$	$w$	$:\tau(w)$
	$  expr_1 \rightarrow expr_2$	$:\tau \times \tau \rightarrow Bool$
	$  \text{objectUndefined}(expr_1)$	$:\tau \rightarrow Bool$
	$  \{ \{ expr_1, \dots, expr_n \}$	$:\tau \times \dots \times \tau \rightarrow Set(\tau)$
	$  \text{set}(expr_1)$	$: Set(\tau) \rightarrow Int$
	$  \text{allInstancesOf}$	$: Set(\tau_2)$
	$  \text{if}(expr_1)$	$:\tau_2 \rightarrow \tau_2$
	$  \text{if}_1(expr_1)$	$:\tau_2 \rightarrow \tau_2$
	$  \text{if}_2(expr_1)$	$:\tau_2 \rightarrow Set(\tau_2)$
	$  \text{true}, \text{false}$	$: Bool$
	$  \text{inv } expr_1$	$: Bool \rightarrow Bool$
	$  \text{expr}_1 \{ \text{and/or/implies} \} expr_2$	$: Bool \times Bool \rightarrow Bool$
	$  \dots$	$:\tau$
	$  \text{ObjectUndefined}$	$:\tau$
	$  \text{context } inv : T_1, \dots, w_1, T_2 = expr_2   expr_3$	$: Set(\tau_2) \rightarrow \tau_2$
	$  \text{context } inv : T_1, \dots, w_1, T_2, inv : expr$	$: Bool$

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### Recall: Vending Machine Structure

$\mathcal{S} = ((Bool, Int), (VM, CR, DD), \{cp : CP, dd : DD, w : Bool, vis : Nat\}, \{VM \rightarrow \{cp, dd\}, CP \rightarrow \{w, dd\}, DD \rightarrow \{vis\}\})$



Claim: this is a proper OCL constraint over  $\mathcal{S}$ .

$\text{context } CP \text{ inv : } w \wedge \text{implies } dd \cdot vis > 0$

$\mathcal{S} \models \text{context } CP \text{ inv : } w \wedge \text{implies } dd \cdot vis > 0$   
 $\mathcal{S} \models \forall (cp : CP) \cdot \forall (dd : DD) \cdot \forall (w : Bool) \cdot \forall (vis : Nat) \cdot (w \wedge \text{implies } dd \cdot vis > 0)$

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### Plan

$expr ::=$	$w$	$:\tau(w)$
	$  expr_1 \rightarrow expr_2$	$:\tau \times \tau \rightarrow Bool$
	$  \text{objectUndefined}(expr_1)$	$:\tau \rightarrow Bool$
	$  \{ \{ expr_1, \dots, expr_n \}$	$:\tau \times \dots \times \tau \rightarrow Set(\tau)$
	$  \text{set}(expr_1)$	$: Set(\tau) \rightarrow Int$
	$  \text{allInstancesOf}$	$: Set(\tau_2)$
	$  \text{if}(expr_1)$	$:\tau_2 \rightarrow \tau_2$
	$  \text{if}_1(expr_1)$	$:\tau_2 \rightarrow \tau_2$
	$  \text{if}_2(expr_1)$	$:\tau_2 \rightarrow Set(\tau_2)$
	$  \text{true}, \text{false}$	$: Bool$
	$  \text{inv } expr_1$	$: Bool \rightarrow Bool$
	$  \text{expr}_1 \{ \text{and/or/implies} \} expr_2$	$: Bool \times Bool \rightarrow Bool$
	$  \dots$	$:\tau$
	$  \text{ObjectUndefined}$	$:\tau$
	$  \text{context } inv : T_1, \dots, w_1, T_2 = expr_2   expr_3$	$: Set(\tau_2) \rightarrow \tau_2$
	$  \text{context } inv : T_1, \dots, w_1, T_2, inv : expr$	$: Bool$

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(Core) OCL Syntax OMG (2006)

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When given  $\mathcal{S} = (\mathcal{F}, \mathcal{K}, V, \text{dir})$ ,

- $w \in W \supseteq \{\text{nil}; c; \tau c; \mid C \in \mathcal{K}\}$  is a set of typed logical variables, w has type  $\tau(w)$
- $\tau$  is the way type from  $\mathcal{F} \cup \mathcal{T} \cup \mathcal{U} \mathcal{T} \mathcal{K} \cup \{\text{Set}(n) \mid n \in \mathcal{F} \cup \mathcal{T} \cup \mathcal{U} \mathcal{T} \mathcal{K}\}$  to  $\mathcal{T}$
- $\mathcal{T}$  is a set of OCL base types.
- In the following we use
  - $T_0 = \{\text{Bool}, \text{Int}, \text{String}\}$
  - $T_0$  is the set of object types.
  - $\text{Set}(n)$  denotes the set of  $n$ -types
  - Type for  $n_0 \in \mathcal{T} \cup \mathcal{U} \mathcal{T} \mathcal{K}$  is denoted by  $\tau(n_0)$ .

Each expression

$\text{nil}(c, D_1)$	: $\tau c \rightarrow \tau$	where $w : \tau \in \text{dir}(C), + \in \mathcal{F}$
$\text{nil}(c, D_1)$	: $\tau c \rightarrow \tau_0$	where $n_1 : D_{n_1} \in \text{dir}(C), C, D \in \mathcal{K}$
$\text{nil}(c, D_1)$	: $\tau c \rightarrow \text{Set}(T_0)$	where $n_2 : D_{n_2} \in \text{dir}(C), C, D \in \mathcal{K}$

where given  $\mathcal{S} = (\mathcal{F}, \mathcal{K}, V, \text{dir})$ ,

- $w \in W \supseteq \{\text{nil}; c; \tau c; \mid C \in \mathcal{K}\}$  is a set of typed logical variables, w has type  $\tau(w)$
- $\tau$  is the way type from  $\mathcal{F} \cup \mathcal{T} \cup \mathcal{U} \mathcal{T} \mathcal{K} \cup \{\text{Set}(n) \mid n \in \mathcal{F} \cup \mathcal{T} \cup \mathcal{U} \mathcal{T} \mathcal{K}\}$  to  $\mathcal{T}$
- $\mathcal{T}$  is a set of OCL base types.
- In the following we use
  - $T_0 = \{\text{Bool}, \text{Int}, \text{String}\}$
  - $T_0$  is the set of object types.
  - $\text{Set}(n)$  denotes the set of  $n$ -types
  - Type for  $n_0 \in \mathcal{F} \cup \mathcal{T} \cup \mathcal{U} \mathcal{T} \mathcal{K}$  is denoted by  $\tau(n_0)$ .

Notational Conventions for Expressions

- Each expression  $e_1, e_2, \dots, e_n$  may alternatively be written ("abbreviated as")  $e_1 \times e_2 \times \dots \times e_n$
- $\text{exp}_1, \dots, \text{exp}_n$  If  $\tau$  is an object type, ie if  $\tau \in T_0$
- $\text{exp}_1 \rightarrow \dots \rightarrow \text{exp}_n$  If  $\tau$  is a collection type (ie a set only), ie if  $\tau = \text{Set}(n)$  for some  $n_0 \in \mathcal{T} \cup \mathcal{U} \mathcal{T} \mathcal{K}$ .

Examples:  $\{\{ \text{Int} \}, \{ C, D \}, \{ x : \text{Int}, p : C_1, m : C_2 \}, \{ C \rightarrow \{ n \}, D \rightarrow \{ x \} \}$

- $\text{nil}(c; p) \rightarrow p(\text{Set}(C))$
- $\text{nil}(c; p; n) \rightarrow \text{nil}(\text{exp}_1; \dots; \text{exp}_n)$
- context CP inv:  $\text{var } n$  implies  $\text{dir. var } n \geq 0$  ( $\text{dir}(CP) = \{\text{var } n : \text{Bool}, \text{dir. } D_{n_1}\}$ )

Expression Examples

$\text{exp}_1 := \dots$	: $\tau(w)$	$ \text{Set}(c, D_1) $	: $\text{Set}(T) \rightarrow \text{Int}$
$\text{exp}_1 = \text{exp}_2$	: $\tau \times \tau \rightarrow \text{Bool}$	$ \text{allInstance} $	: $\text{Set}(T) \rightarrow \text{Int}$
$ \text{occUndefined}(c, D_1) $	: $\tau \times \tau \rightarrow \text{Bool}$	$ \text{nil}(c, D_1) $	: $\tau c \rightarrow \tau(t)$
$ \{ \text{exp}_1, \dots, \text{exp}_n \} $	: $\tau \times \dots \times \tau \rightarrow \text{Set}(T)$	$ \tau_1(c, D_1) $	: $\tau c \rightarrow \tau_0$
$ \text{Set}(m, p, n) $	: $\text{Set}(T) \rightarrow \text{Bool}$	$ \tau_2(c, D_2) $	: $\tau c \rightarrow \text{Set}(T_0)$

$\mathcal{S}_0 = (\{\text{Int}\}, \{C, D\}, \{x : \text{Int}, p : C_1, m : C_2\}, \{C \rightarrow \{n\}, D \rightarrow \{x\}\})$

- $\text{allInst} : \text{Int} \checkmark$
- $\text{nil}(c; p) : \text{Int} \checkmark$
- $\text{nil}(c; p; n) \times \text{nil}(c; p) \checkmark$
- $\text{nil}(c; p; n) : \tau c \rightarrow \tau_0 \checkmark$
- $\text{nil}(c; p; n) : \tau c \rightarrow \text{Set}(T_0) \checkmark$
- $\text{nil}(c; p; n) : \tau c \rightarrow \text{Set}(C_1) \checkmark$
- $\text{nil}(c; p; n) : \tau c \rightarrow \text{Set}(C_2) \checkmark$

OCL Syntax 2/A: Constants & Arithmetics

For example

$\text{exp}_1 := \dots$	: $\text{Bool}$
$\text{true}$	: $\text{Bool}$
$\text{exp}_1 \{ \text{and, or, implies} \} \text{exp}_2$	: $\text{Bool} \times \text{Bool} \rightarrow \text{Bool}$
$\text{not exp}_1$	: $\text{Bool} \rightarrow \text{Bool}$
$\{0, -1, 1, -2, 2, \dots\}$	: $\text{Int}$
$\text{exp}_1 \{+, \dots\} \text{exp}_2$	: $\text{Int} \times \text{Int} \rightarrow \text{Int}$
$\text{exp}_1 \{<, \leq, \dots\} \text{exp}_2$	: $\text{Int} \times \text{Int} \rightarrow \text{Bool}$
$ \text{OccUndefined} $	: $\tau$

Generalised notation (only normal form)

with  $w \in \{\dots, \dots\}$

$\text{exp}_1 := \dots$  :  $\tau_1 \times \dots \times \tau_n \rightarrow \tau$

Expression Examples

$\text{exp}_1 := \dots$	: $\tau(w)$	$ \text{Set}(c, D_1) $	: $\text{Set}(T) \rightarrow \text{Int}$
$\text{exp}_1 = \text{exp}_2$	: $\tau \times \tau \rightarrow \text{Bool}$	$ \text{allInstance} $	: $\text{Set}(T) \rightarrow \text{Int}$
$ \text{occUndefined}(c, D_1) $	: $\tau \times \tau \rightarrow \text{Bool}$	$ \text{nil}(c, D_1) $	: $\tau c \rightarrow \tau(t)$
$ \{ \text{exp}_1, \dots, \text{exp}_n \} $	: $\tau \times \dots \times \tau \rightarrow \text{Set}(T)$	$ \tau_1(c, D_1) $	: $\tau c \rightarrow \tau_0$
$ \text{Set}(m, p, n) $	: $\text{Set}(T) \rightarrow \text{Bool}$	$ \tau_2(c, D_2) $	: $\tau c \rightarrow \text{Set}(T_0)$

$\mathcal{S}_0 = (\{\text{Int}\}, \{C, D\}, \{x : \text{Int}, p : C_1, m : C_2\}, \{C \rightarrow \{n\}, D \rightarrow \{x\}\})$

context CP inv:  $\text{var } n$  implies  $\text{dir. var } n \geq 0$

Constants & Arithmetics Examples

$\text{exp}_1 := \dots$	: $\text{Bool}$
$\text{true}$	: $\text{Bool} \times \text{Bool} \rightarrow \text{Bool}$
$\text{exp}_1 \{ \text{and, or, implies} \} \text{exp}_2$	: $\text{Bool} \times \text{Bool} \rightarrow \text{Bool}$
$\text{not exp}_1$	: $\text{Bool} \rightarrow \text{Bool}$
$\{0, -1, 1, -2, 2, \dots\}$	: $\text{Int}$
$\text{exp}_1 \{+, \dots\} \text{exp}_2$	: $\text{Int} \times \text{Int} \rightarrow \text{Int}$
$\text{exp}_1 \{<, \leq, \dots\} \text{exp}_2$	: $\text{Int} \times \text{Int} \rightarrow \text{Bool}$
$ \text{OccUndefined} $	: $\tau$

$\mathcal{S}_0 = (\{\text{Int}\}, \{C, D\}, \{x : \text{Int}, p : C_1, m : C_2\}, \{C \rightarrow \{n\}, D \rightarrow \{x\}\})$

implic (var, > (var, dir, 0))

$\text{dir. var } n \geq 0$

context CP inv:  $\text{var } n$  implies  $\text{dir. var } n \geq 0$

### OCL Syntax 3/4: Iterate

$expr ::= \dots \mid expr_1 \rightarrow \text{iterate}(u_1 : T_1, u_2 : T_2 = expr_2 \mid expr_3)$

or with a little renaming

$expr ::= \dots \mid expr_1 \rightarrow \text{iterate}(iter : T_1, result : T_2 = expr_2 \mid expr_3)$

where

- $expr_1$  is of a **collection type** (here a set  $Set(O)$  for some  $o$ ).
- $iter \in W$  is called **iterator**, of the type denoted by  $T_1$ .
- (if  $T_1$  is  $exp_{1,iter}$ ,  $iter$  is assumed as type of  $iter$ )
- $result \in W$  is called **result variable**, gets type  $\tau_2$  denoted by  $T_2$ .
- $expr_2$  is an expression of type  $\tau_2$ , giving the initial value for  $result$ .
- (OCLUndefined $\tau_2$ , if omitted)
- $expr_3$  is an expression of type  $\tau_2$ .
- in particular  $iter$  and  $result$  may appear in  $expr_3$ .

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### Iterate Example

$\mathcal{S} = (\{Bool, Int\}, \{VM, CR, DD\},$   
 $\{cp : CP, add : DD_{0,1}, werr : Bool, wss : Nat\},$   
 $\{VM \mapsto \{cp, add\}, CP \mapsto \{werr, dd\}, DD \mapsto \{wss\}\})$



$expr ::= expr_1 \rightarrow \text{iterate}(u_1 : T_1, u_2 : T_2 = expr_2 \mid expr_3)$

$cp(\text{add}) \rightarrow \text{iterate}(iter : Int = 0 \mid res + \text{Int.add } wss)$   
 $\text{Set}(CP)$   
 $cp(\text{add}) \rightarrow \text{iterate}(iter, res : Bool = true \mid res \text{ and } \text{Int.add } wss)$

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### Abbreviations on Top of Iterate

$expr ::= expr_1 \rightarrow \text{iterate}(u_1 : T_1, u_2 : T_2 = expr_2 \mid expr_3)$

$expr_1 \rightarrow \text{forall}(u : T_1 \mid expr_2) \quad (\forall u \in \mathcal{U} \bullet expr_2 \bullet expr_3)$

is an abbreviation for

$expr_1 \rightarrow \text{iterate}(u_1 : T_1, u_2 : Bool = true \mid u_2 \text{ and } expr_2)$

$expr_1 \rightarrow \text{exists}(u : T_1 \mid expr_2)$

is an abbreviation for

$cp_1 \rightarrow \text{iterate}(u_1 : T_1, u_2 : Bool = false \mid u_2 \text{ or } expr_2)$

To ensure confusion, we may again omit all kinds of things: cf. OMG 00061

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### Recall: Overview

$expr ::= w$	$\tau(w)$
$[expr_1 \mapsto expr_2]$	$\tau \times \tau \rightarrow Bool$
$[OCLUndefined(expr_1)]$	$\tau \rightarrow Bool$
$\{ \{expr_1, \dots, expr_n\} \}$	$\tau \times \dots \times \tau \rightarrow Set(\tau)$
$[Set(expr_1)]$	$Set(\tau) \rightarrow Bool$
$[allInstances(expr_1)]$	$Set(\tau)$
$[v(expr_1)]$	$\tau \rightarrow \tau$
$[r_1(expr_1)]$	$\tau \rightarrow \tau$
$[r_2(expr_1)]$	$\tau \rightarrow Set(\tau)$
$[true, false]$	$Bool$
$[not expr_1]$	$Bool \rightarrow Bool$
$[expr_1 \text{ and/or/implies } expr_2]$	$Bool \times Bool \rightarrow Bool$
$\dots$	$\dots$
$[OCLUndefined]$	$\tau$
$[expr_1 \rightarrow \text{iterate}(u_1 : T_1, u_2 : T_2 = expr_2 \mid expr_3)]$	$Set(O) \rightarrow \tau_2$
$context ::= [context u_1 : T_1, \dots, u_n : T_n, inv : expr]$	$Bool$

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### More Iterate Examples

$\mathcal{S} = (\{Bool, Int\}, \{VM, CR, DD\},$   
 $\{cp : CP, add : DD_{0,1}, werr : Bool, wss : Nat\},$   
 $\{VM \mapsto \{cp, add\}, CP \mapsto \{werr, dd\}, DD \mapsto \{wss\}\})$



$expr ::= expr_1 \rightarrow \text{iterate}(u_1 : T_1, u_2 : T_2 = expr_2 \mid expr_3)$

all instances  $CP \rightarrow \text{iterate}(iter : CP, res : Bool = true \mid$   
 $res \text{ and } (iter \text{ var } \text{ implies } \text{add } wss > 0))$   
 or  
 all instances  $CP \rightarrow \text{forall}(iter : CP, res : Bool = true \mid$   
 $iter \text{ var } \text{ implies } \text{add } wss > 0)$

context  $CP$  inv: var implies add wss > 0

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### OCL Syntax 4/4: Context

**Syntax** (binding signature  $\mathcal{S} = (S, F, A, D)$ )

$context ::= context(u_1 : T_1, \dots, u_n : T_n, inv : expr)$

where  $T_i \in \mathcal{C}$  and  $u_i : T_i \in W$  for all  $1 \leq i \leq n, n \geq 0$ .

**Semantics**

is (just) an abbreviation for

$context(u_1 : C_1, \dots, u_n : C_n, inv : expr)$   
 $\dots$   
 $\text{allInstances}_1 \rightarrow \text{forall}(u_1 : \mathcal{C}_1 \mid$   
 $\dots$   
 $\text{allInstances}_n \rightarrow \text{forall}(u_n : \mathcal{C}_n \mid$   
 $expr$   
 $)$   
 $\dots$   
 $)$

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- For
  - context  $self : T, inv : capr$
  - we may **alternatively** write ("abbreviate as")
    - context  $T, inv : capr$
- Within** the liter abbreviation, we may omit the "self" in expression  $expr$ , i.e. for
  - context  $T, inv : self, x$
  - which is an abbreviation for context  $T, inv : x(self)$
- we may **alternatively** write ("abbreviate as")
  - context  $T, inv : x$

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```

context CP inv : user implies del_val > 0
context self : CP inv, user implies del_val > 0
context self : CP inv, self.user implies self.del_val > 0
self.del_val > 0 → self.del_val > 0 | self.user implies self.del_val > 0
-- .. Header (....)

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expr ::= w
       | capr₁ = capr₂
       | !defined(⟦expr⟧)
       | {capr₁, ..., caprₙ}
       | !size capr₁
       | !liveness
       | !⟦capr₁⟧
       | !⟦capr₁⟧
       | !⟦capr₁⟧
       | true false
       | !not capr₁
       | capr₁ (and/or implies) capr₂
       | ...
       | !!defined
       | capr₁ → !herald (w : T₁, w₂ : T₂ = capr₂ | caprₙ) : Set(n) → T₂
context ::= context w₁ : T₁, ..., wₙ : Tₙ, inv : capr

```

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"Not Interesting"

- Among others
  - Enumeration types
  - Type hierarchy
  - Complete list of arithmetical operators
  - The two other collection types Bag and Sequence
  - Casting
  - Runtime type information
  - Pre/post conditions
  - (maybe later, when we officially know what an operation is)
    - context  $f$  pre : capr₁
    - post : capr₂

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References

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